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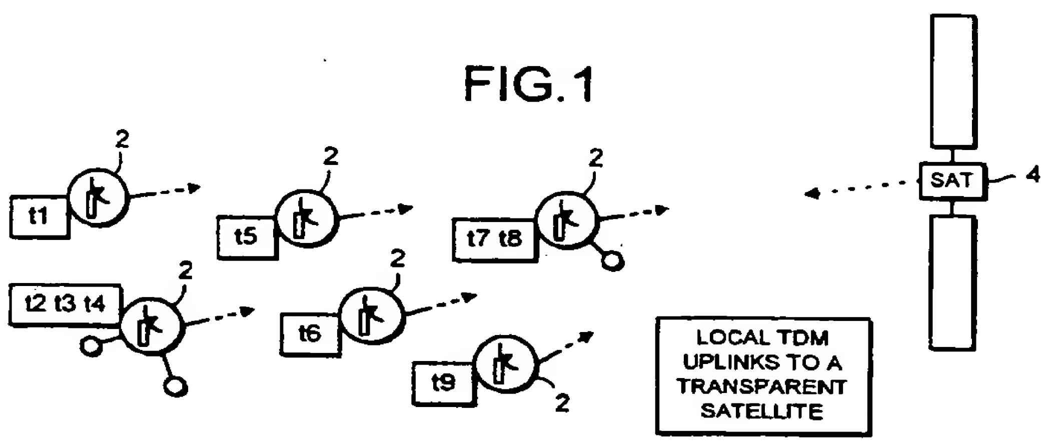
(54) Abstract Title
**Digital broadcast systems**

(57) A multi-carrier signal has a regular frame structure and symbol rate and is comprised of contributions from a plurality of different transmitters (2). The contributions from each transmitter are transmitted to a central transmitter (4) in pre-assigned time slots. The received contributions are then re-transmitted as a single signal over a pretermined area of coverage with a dummy symbol inserted at the start of each contribution in the frame for use as a phase reference for demodulating succeeding symbols in that contribution.

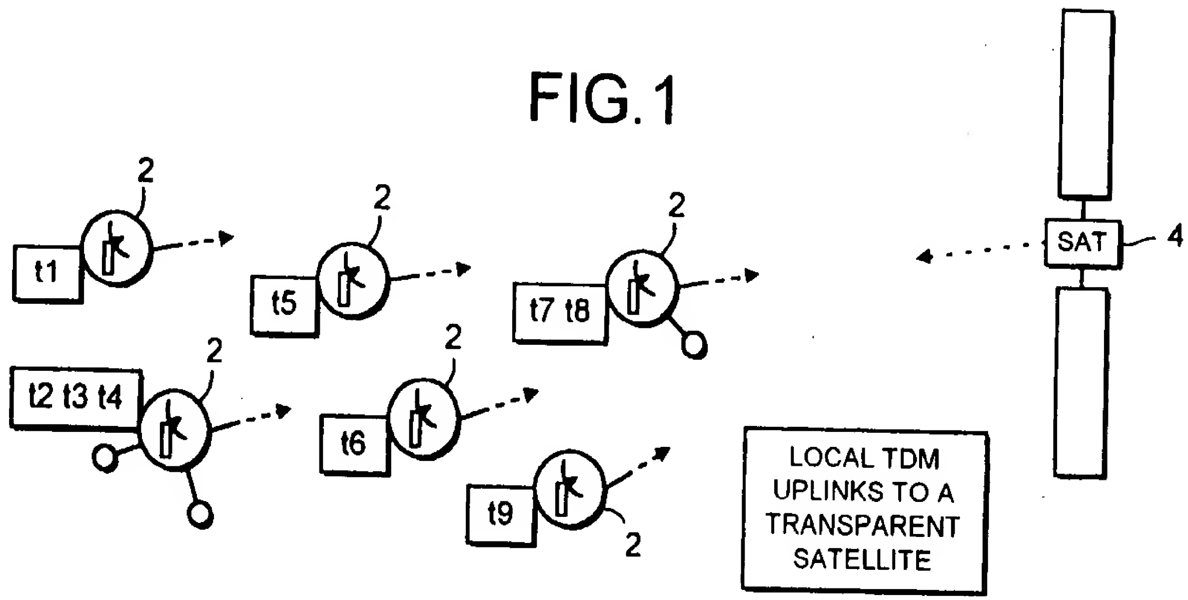
FIG.1




GB 2 330 491 A

At least one drawing originally filed was informal and the print reproduced here is taken from a later filed formal copy.

FIG.1


2
4
SAT
t1
t5
t7 t8
t2 t3 t4
t6
t9
LOCAL TDM
UPLINKS TO A
TRANSPARENT
SATELLITE

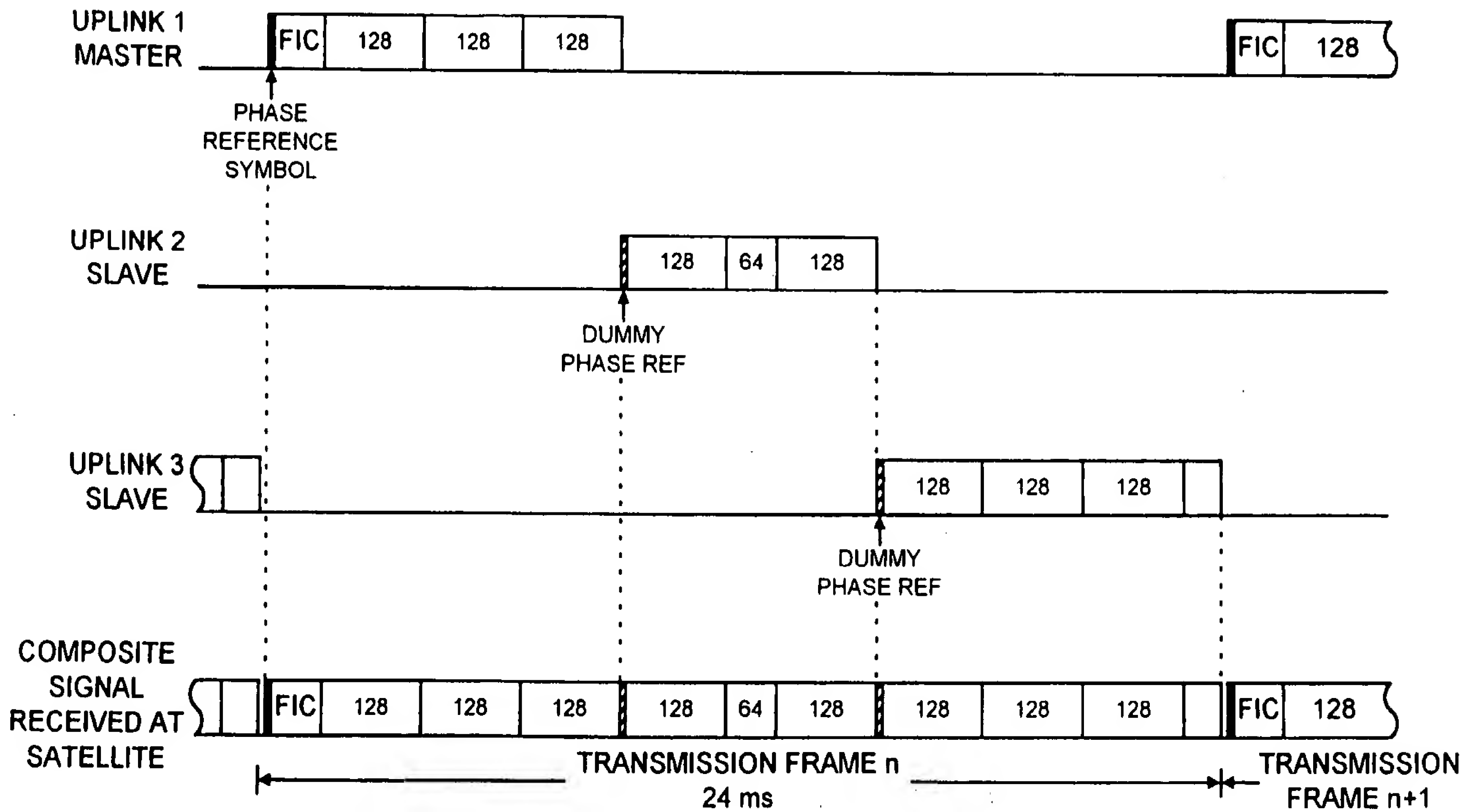

UPLINK 1
MASTER
FIC
128
128
128
FIC
128
PHASE
REFERENCE
SYMBOL
UPLINK 2
SLAVE
128
64
128
DUMMY
PHASE REF
UPLINK 3
SLAVE
128
128
128
DUMMY
PHASE REF
COMPOSITE
SIGNAL
RECEIVED AT
SATELLITE
FIC
128
128
128
128
64
128
128
128
128
FIC
128
TRANSMISSION FRAME n
24 ms
TRANSMISSION
FRAME n+1

FIG. 2

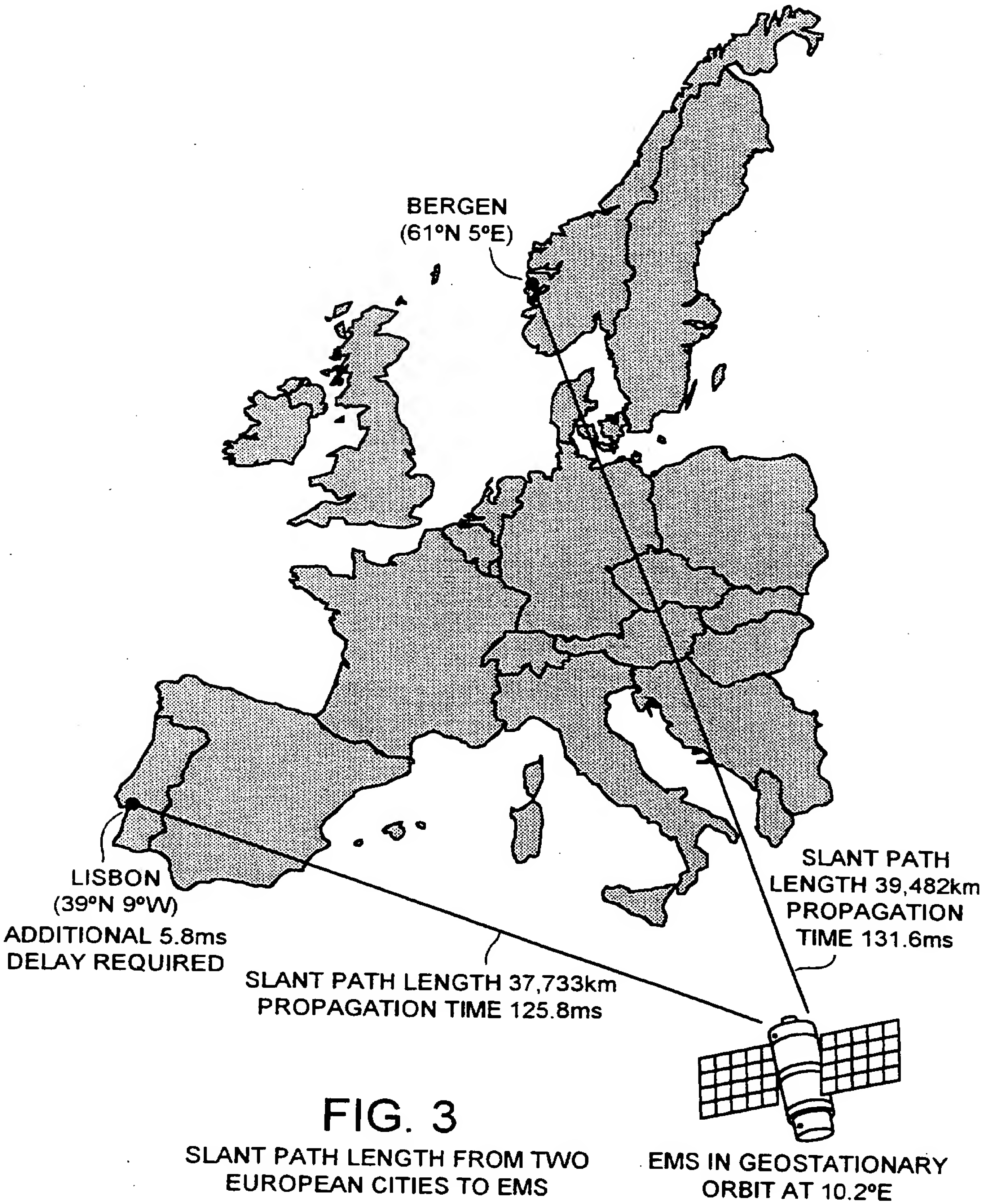



FIG. 3

SLANT PATH LENGTH FROM TWO EUROPEAN CITIES TO EMS

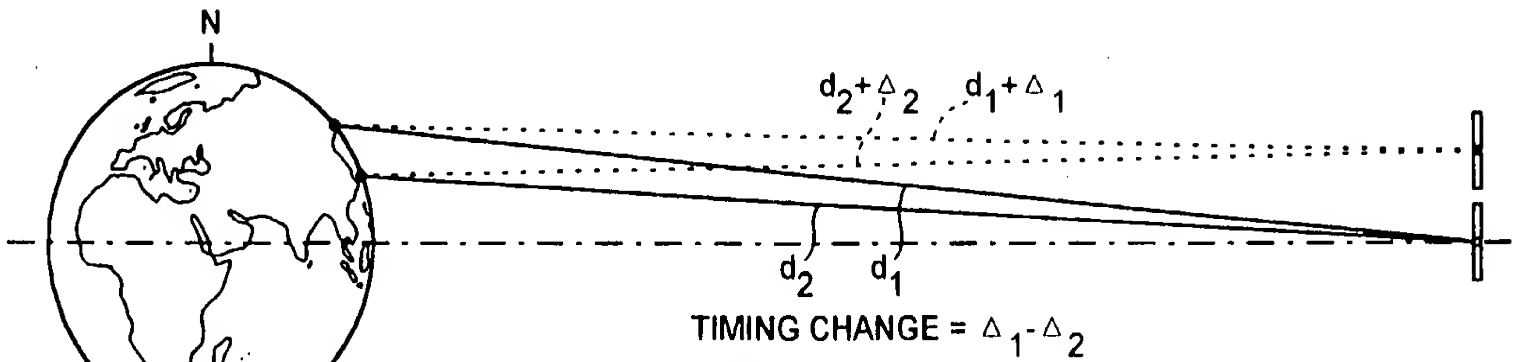



FIG. 4

DIFFERNTIAL RANGE ERROR

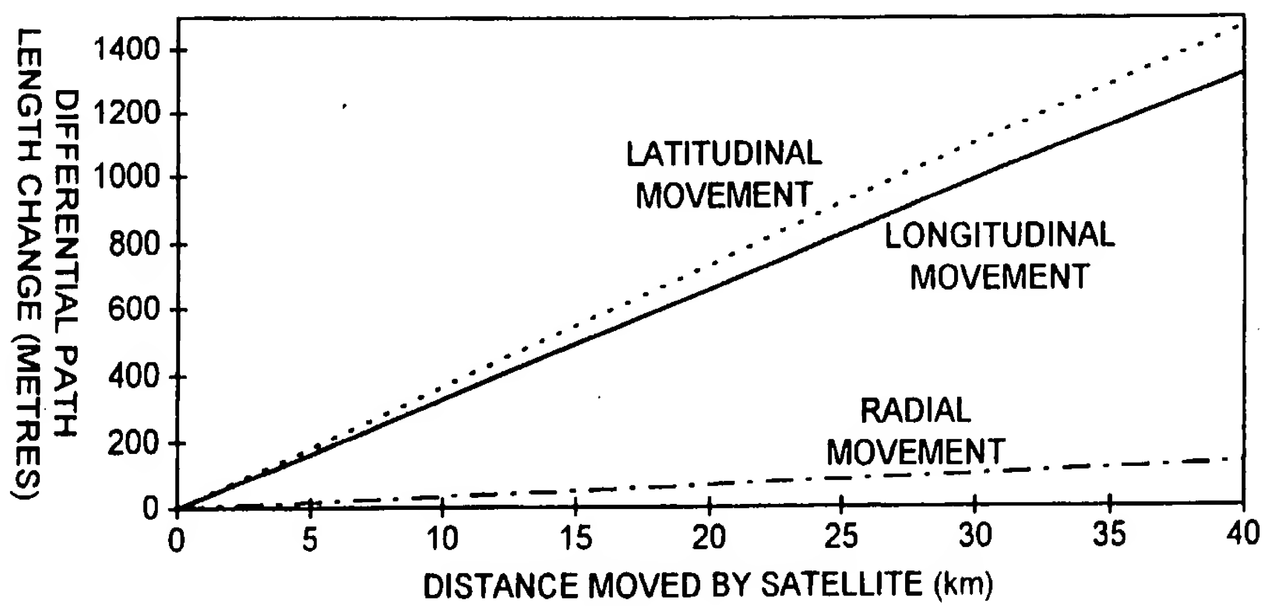



FIG. 5

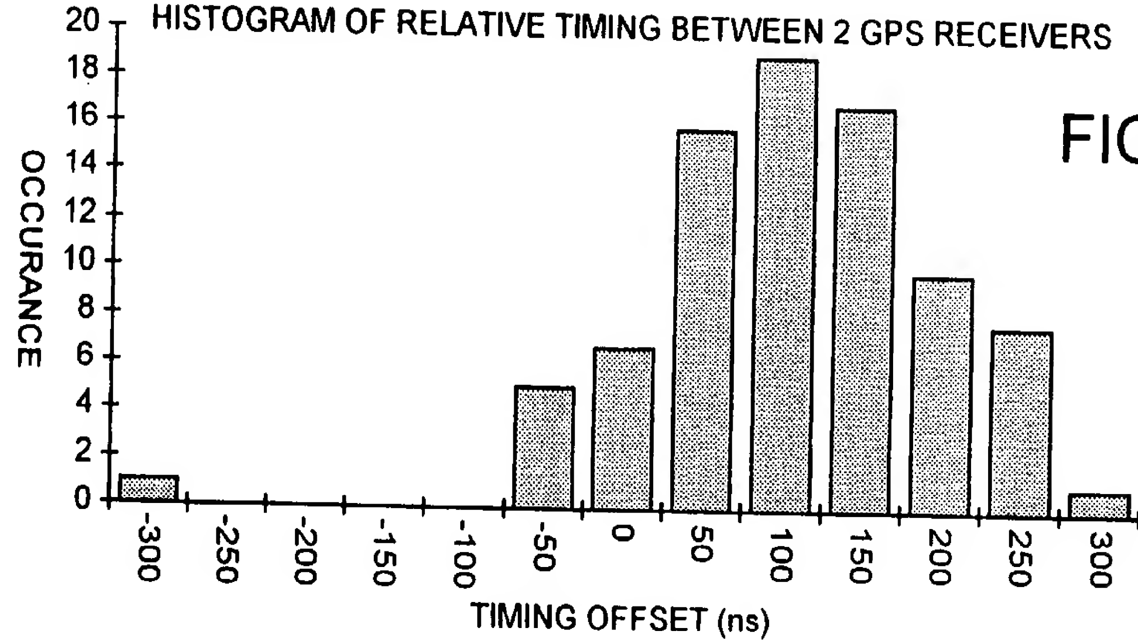

HISTOGRAM OF RELATIVE TIMING BETWEEN 2 GPS RECEIVERS
OCCURANCE
20
18
16
14
12
10
8
6
4
2
0
-300
-250
-200
-150
-100
-50
0
50
100
150
200
250
300
TIMING OFFSET (ns)

FIG. 6

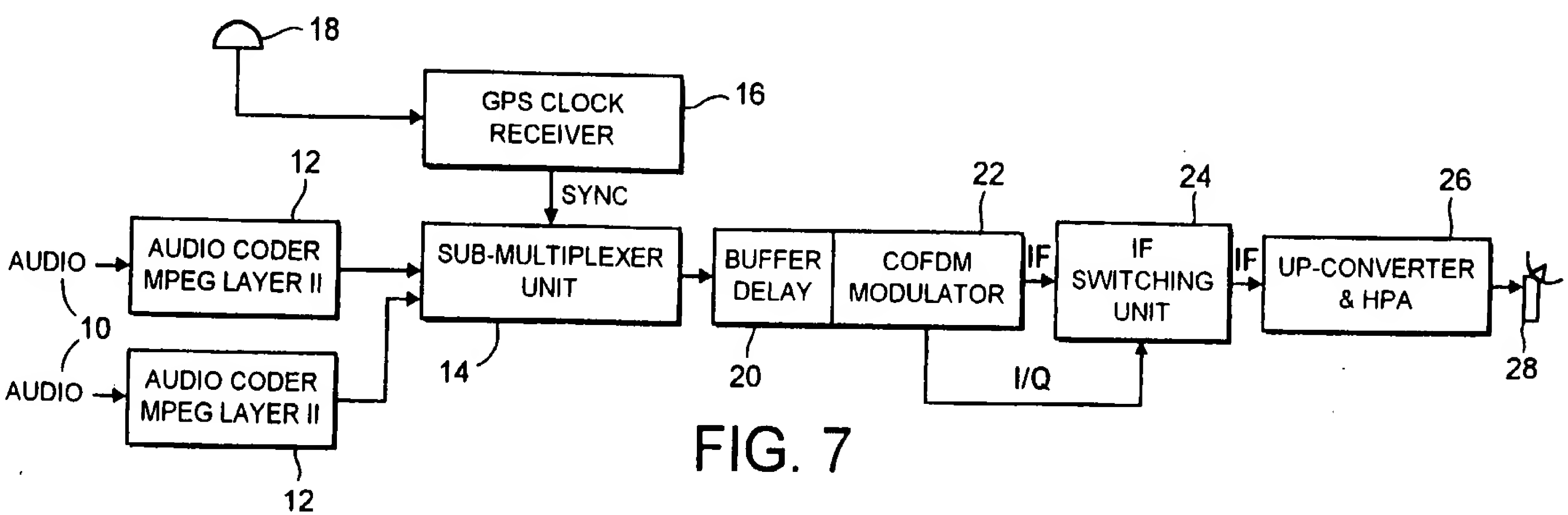

18
GPS CLOCK RECEIVER
16
SYNC
12
AUDIO
AUDIO CODER MPEG LAYER II
10
AUDIO
AUDIO CODER MPEG LAYER II
12
SUB-MULTIPLEXER UNIT
14
BUFFER DELAY
20
COFDM MODULATOR
22
IF
IF SWITCHING UNIT
24
I/Q
IF
UP-CONVERTER & HPA
26
28

FIG. 7

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# DIGITAL BROADCAST SYSTEMS

This invention relates to digital broadcast systems such as digital audio broadcast (DAB) and in particular to a system which enables digital broadcasts from two or more different broadcasters to be combined in a single broad band transmission.

The Eureka-147 DAB system which has been proposed as a practical implementation of digital audio broadcasting operates by using a coded orthogonal frequency division multiplexed (COFDM) system. In this, a large number of carriers are spread over a broad frequency band to carry digital data. Each carrier is modulated with the data so as to carry two bits of data by using quadrature phase shift keying (QPSK). Groups of these carriers are then transformed to the time domain by a Fast Fourier transform to produce what is known as a DAB symbol. A plurality of these symbols are assembled and between them are able to carry data from a large number of channels. The symbols are transmitted together in a DAB frame or multiplex comprising a series of symbols and which commences and terminates with a null symbol for synchronisation. A typical transmission bandwidth of 1.53 MHz can typically accommodate 5 or 6 channels.

Satellite delivery of digital broadcasts is seen as an attractive option for international broadcasters because it provides coverage of large areas at relatively low costs.

Because a Eureka-147 DAB ensemble carries not just one but several audio channels or other services, several co-operating broadcasters would need to share an ensemble between them. This can be relatively easily accomplished at a national level where there are both national and

local broadcasters by leaving free symbols in national broadcasts into which local broadcasters can insert data. These would typically be combined at a single site and can then be transmitted over the relevant area.

Where it is desired to combine broadcasting over a number of different countries, e.g. UK, France, Germany and Austria, and transmit them as a single DAB ensemble over all of those countries, the combination at a single terrestrial uplink site becomes impractical because of the cost of terrestrial data lines.

One solution is to use a dedicated satellite with an on-board processor to which all the broadcasters transmit. The satellite then combines all the data and produces a single DAB ensemble from this. The problem with this, of course, is that a dedicated satellite has to be launched in order for the system to become operational.

A preferred embodiment of the present invention provides a system in which a number of different broadcasters each transmit a section of a COFDM ensemble from an uplink site to a conventional satellite in time division multiplex slots. The satellite then amplifies and frequency shifts the received signals before transmitting them over its area of coverage. No on-board processing is involved other than would be used for a conventional radio transmission. Each uplink site would need to be adequately synchronised to the others so that the resulting composite COFDM signal appeared seamless when transmitted by the satellite. This can easily be achieved using the global position system (GPS).

The invention is defined with more precision in the appended claims to which reference should now be made.

The invention will now be described in detail by way of example with reference to the accompanying drawings in which:

**Figure 1** shows schematically a number of uplink sites transmitting signals to a conventional satellite in time division multiplex (TDM) slots for retransmission over the satellite's area of coverage in an embodiment of the invention;

**Figure 2** shows schematically the combination of DAB symbols from three different uplink sites in accordance with an embodiment of the invention;

**Figure 3** shows schematically the different slant path lengths from two European cities to a satellite in geostationary orbit;

**Figure 4** shows the differential range for a satellite in geostationary orbit;

**Figure 5** is a graph showing the relationship between differential path length and the distance moved by the satellite;

**Figure 6** is a histogram showing relative timings between 2 GPS receivers; and

**Figure 7** is a block diagram of an uplink site of the type shown in Figure 1.

It is envisaged that in an embodiment of this invention a multiplexed uplink system would involve two or more uplink sites of the type shown in Figure 1. These can be receiving one or more signals, coding them with COFDM and transmitting them in preassigned time slots to a satellite. Each uplink site provides a portion of the COFDM signal directly to the satellite. The multi carrier nature of the Eureka DAB signal with its frequency and time interleaving means that mapping of a particular bit

pair onto a particular carrier is very complex. Whilst it would be technically possible to identify which carriers are associated with each uplink contribution, it would then be necessary to be able to suppress each carrier on an individual basis. This would be considerably more difficult than switching all of the carriers on and off simultaneously at single symbol boundaries. As will be seen, this is not a severe constraint and greatly simplifies the handover process.

A time division multiplex system of the type embodying the present invention requires a fairly radical rethink of the requirements of the DAB transmission chain. The TDM system requires complete shutdown of the transmitters RF output at frequent and regular intervals. At present there is no structure to enable the COFDM generator to switch off all the carriers at selective times. Inserting zeros into the multiplex is not the solution since the carriers are phase modulated and this would generate a symbol representing a digital zero. Therefore, TDM operation produces a requirement for a 3-stage control of the COFDM transmitter output, a digital one, a digital nought, and a suppressed carrier. This can be done in two ways.

In the first method, the symbols which are not going to be transmitted from the specified uplink are filled with dummy data and the RF output of the COFDM generator is switched off for the duration of the other contributions. As the contributing uplink sources only need to switch at a symbol boundary, this option is relatively simple. A small amount of logic is required to count through the symbols of each frame and switch at the appropriate time.

The second method is to configure the multiplexer and COFDM generator internally to switch off the unwanted carriers for the required time. The configuration is controlled from the multiplexing unit and a new interface to the COFDM generator. A new control mechanism would be required if the multiplexer was to be able to control adequately the COFDM generator. This requires access to the software on both devices.

In the TDM uplink arrangement, the transition points between the separate uplink signals as received at the satellite deserve special consideration. Apart from the problems of synchronisation, there is the problem introduced by the use of differential QPSK modulation. The receivers which are proposed for use with the signal decode each symbol in the ensemble with reference to the phase of the previous symbol (except for the first symbol of every transmission frame which is the fixed reference symbol). This is transmitted by uplink station number 1, the master, and is shown in Figure 2.

The other uplink sites are called slaves. Data uplinked by these slave stations cannot be differentially decoded from the beginning because the previous symbol will originate from a different uplink site and will therefore have no useful phase relationship. Because of this, the first symbol of a slave contribution cannot be differentially decoded to provide any useful data. However, its phase state does then become the reference for the second symbol, thereby allowing the remaining symbols from that uplink contribution to be decoded as normal.

To solve this problem, a dummy phase reference symbol is inserted at the start of each slave contribution as shown in Figure 2. The multiplexer can easily be

configured to insert a dummy service component occupying just a single symbol which it fills with random data or any other data. As the system is differentially modulated, the following symbol will be demodulated with reference to the dummy symbol.

The system of Figure 2 shows three multiplex uplink sites carrying contributions of 128 K-bits/s and 64 K-bits/s as part of a TDM arrangement. The lower line of the diagram shows how the dummy phase reference signals inserted by each slave uplink site become part of the overall composite signal received and retransmitted by the satellite.

Loss of the first symbol of each uplink contribution is not a great problem. In Mode III DAB there is a low data-rate per symbol and this means that only 384 bits are lost for each slave uplink. This amounts to just under 0.7% per symbol and an arrangement using 10 geographically separate uplink sites (i.e. one master and nine slaves) would reduce the user capacity by only 6.25%.

Although a transitional dummy phase reference symbol cannot be used to carry any useful data, it may be used for carrying status information between uplink sites (by using a non-standard receiver).

The composite signal transmitted from the satellite will be the combined result of the several different uplink stations. However, it must not exhibit any artefacts of its TDM origination. Three fundamental parameters which must be kept as constant as possible are:

1. synchronisation
2. uplink frequency
3. power level.

The handover between uplinks must not create overlaps or gaps in the signal, the power level must be constant throughout the transmission frame, and the frequency for each uplink must be the same so as not to create any discontinuity. That is to say, the final signal reaching the receiver must appear to be the result of a single transmission chain, rather than the combination of several contributing uplinks.

At the handover point between contributing uplinks, the timing error needs to be accurate to within a fraction of a symbol duration. For Mode III DAB the total symbol duration is 156 microseconds, (which includes a guard interval of 31 $\mu s$). Any "data collision" arising from a mis-aligned uplink would probably cause the loss of some data from both uplinks. In addition, such a data collision would increase the input power to the satellite by 3 dB. Given the finite power capability of a satellite transponder, and the fact that it is likely to be operating close to saturation, this could affect other users of the transponder or even drive the HPA into an overload condition.

A lack of data at the appropriate time could also create problems. In particular, the Eu-147 system uses the null symbol for coarse synchronisation in the time domain, therefore a data gap in the composite signal could be misinterpreted as a null symbol, thereby causing complete synchronisation failure at the receiver, resulting in none of the services on that multiplex being received. Therefore, it is also equally important that a contributing uplink does indeed fill its allocated time-slot.

Various factors must be considered and corrected for to insure that the uplink contributions arrive at the satellite's input antenna at the exact time required.

An uplink site suitable for use in the present invention is shown in figure 7. In this particular example the uplink site is combining two local audio signals for uptransmission to a satellite. Each audio signal is first fed to an MPEG audio coder 12. This compresses the audio data. It is next synchronised in a sub-multiplexor unit 14 which receives a synchronising signal from a global positioning system (GPS) clock receiver 16 which receives the GPS signal via an antenna 18. The multiplexor audio signal is then passed to a buffer delay 20 which feeds them at appropriate intervals to a COFDM modulator 22. This produces a frame of COFDM symbols.

These symbols are supplied to an IF switching unit 24. This counts through the earth COFDM symbols in the frame in response to a clock signal which is supplied by the COFDM modulator 22 in its I/Q bus. The switching by the IF switching unit 24 makes sure that only symbols containing data relating to the two audio signals 10 are passed to an upconverter and high power amplifier 26 which then sends them to an antenna 28 for transmission to the satellite of Figure 1.

It will thus be appreciated that the system of Figure 1 comprises six uplink units similar to that of Figure 7. Four of these are handling only one audio signal, one is handling two audio signals and a final one is handling three audio signals. Each will be synchronised by its GPS clock receiver unit 16 and thus will insert audio data in symbols at different time periods to those used by other

uplink stations such that at the satellite a complete frame of data will be received.

If a more sophisticated receiver is used, the dummy symbol could carry other information. The first portion could be used as the phase reference. For example, a specific data pattern could be included. This could then be monitored by the various uplink sites to aid synchronisation of uplink contributions.

The dummy symbol could also be used as a data channel to feed back, to the uplink site providing the first contribution for each frame, information to go into the Fast Information Channel (FIC) which the first transmitter compiles and which describes the structure of the frame. Thus, it describes which symbols contain data for each channel and, clearly, which symbols are dummy symbols.

Thus, the data is fed to the transmitter compiling the FIC via the satellite. No land line is required.

Other data which could be included in the dummy symbol are an audio channel for communication between the uplink sites or additional data for various commercial services.

Furthermore, at each uplink site a receiver can be provided to monitor the timing and frequency of the dummy symbol it transmitted to the satellite. This can then be used to adjust the timing and frequency of the signal provided by the transmitter.

**Slant Path Length Compensation**

The uplink stations will be located at arbitrary locations on the Earth's surface and will all experience different path lengths to the satellite. In order to create a seamless composite DAB signal the uplink sites with short

path lengths will need compensating delays so that their contributions do not arrive too early.

Given the orbital location of the satellite, and the latitude and longitude of the uplink station, the path length can be readily calculated. Taking a European example, as illustrated in Figure 5:

| | |
|---|---|
| For a satellite at: | 10.2° East |
| Uplink 1: | Lisbon 39°N 9°W |
| Uplink 2: | Bergen 61°N 5°E. |

The nominal difference in the slant path range between the two earth stations and the satellite is 1,749 km, which corresponds to a delay of 5.83 ms.

This could easily be compensated for by delaying the transmission from the Lisbon uplink site (which is closer to the satellite) by an equal amount. (This then allows the placement of the contributing signal at any point in the DAB transmission frame.)

The maximum possible slant path length would be experienced by an earth station on the very edge of the uplink coverage zone where the elevation angle is lowest. It is generally accepted that a minimum earth station antenna elevation angle of 5 degrees is required, and at such a location this gives a maximum possible slant path length of around 41,130 km (corresponding to a one-way propagation time of 138 ms). On the other hand, the *shortest* possible slant path distance would be from an earth station exactly at the sub-satellite point at a range of 35786 km, corresponding to a delay of 120 ms. The location of *any* uplink site can therefore be compensated for using a delay of no more than 18 ms, the

exact figure depending on its geographical location relative to the satellite.

The BBC COFDM generator (CD2M/44) has a built in compensating delay of up to 4 ms, adjustable in increments of 488 ns, while the Marconi-Eddystone COFDM generator can manage a delay of up to 476 ms, adjustable in steps of approximately 1 $\mu$s.

While the difference in the slant path length is the obvious (and major) consideration in synchronising the uplink stations, there are several other factors which affect the accuracy of the timing of each contribution. Some effects will create a common variation in the propagation delay between all the earth stations and the satellite, causing the whole DAB signal to arrive at the incorrect time. Other effects will cause differential errors which adversely change the synchronisation between the uplinked contribution signals.

Although termed "*Geostationary*", a satellite in GEO orbit will always have a tendency to wander a little, due to the Earth's gravitational irregularities, the influence of the Sun and Moon and solar pressure. These perturbations in the satellite's intended position complicate the uplinking of a TDM based system. As the satellite wanders about, the path length from the geographically separate contributing uplink sites will obviously vary. The normal satellite station keeping tolerance is usually quoted as +/-0.05° in each plane, corresponding to maintaining the satellite's position within a cube of sides approximately 80 km. This movement can therefore give the calculated slant path length an error of around +/- 40 km.

If this path length variation was identical for every uplink site then each uplink contribution would arrive at

the satellite slightly 'early' or 'late' but would maintain its place in the DAB frame. The whole broadcast signal would then arrive a few microseconds 'late' or 'early' but there would be no overall effect on synchronisation *between* the uplinks.

But, while the path length change between various uplink sites and the satellite is indeed *largely* the same, any station keeping error will usually create a small but significant *differential* change in these path lengths, which means a synchronisation error would be introduced between the various signals arriving at the satellite. This is illustrated in Figure 4 where $d_1$ and $d_2$ are the original distances from the uplink sites to the satellite, and $\Delta_1$ and $\Delta_2$ are the changes in distance due to orbital drift. If $\Delta_1$ is then different to $\Delta_2$, then a synchronisation error will be introduced.

Satellite station keeping errors can be resolved into three orthogonal planes - latitudinal - i.e. North/South, longitudinal - i.e. East/West, or radial - i.e. towards or away from the Earth. The magnitude of the differential change varies widely depending on the satellite's plane of movement, the location of the uplink sites and the magnitude of the error in the satellite's station keeping.

The maximum possible differential range would be between two uplinks at the extreme (5° elevation) and opposite edges of a global uplink coverage zone, with the satellite moving in the same plane. This would give a differential timing change of 1 $\mu$s/km of satellite movement. In practice, very few uplink sites operate at these extremes and it is likely that most would be within a couple of thousand miles of each other.

Taking the Bergen/Lisbon/EMS example again, the nominal path length difference was shown to be 1,749 km

corresponding to a 5.83 ms fixed delay. Figure 5 shows the differential distance variation between the Bergen and Lisbon uplink paths for variations of the orbital position over the range +/- 0.05° or +/- 40 km in each of the three planes.

For a change in the satellite's latitude, Lisbon, being further south than Bergen, experiences a smaller rate of change of path length than Bergen, and at the extremes the error can be +/- 1344 metres, corresponding to +/- 4.5 $\mu$s (which at 0.06 $\mu$s is a long way short of the theoretical maximum shown above). For a change in the satellite's longitude a similar magnitude of differential error is experienced, while for a radial change in position, both uplink sites experience very similar changes, resulting in little differential error.

The maximum change in timing would therefore occur when the satellite is at its maximum latitudinal error, and maximum longitudinal error and maximum radial error, combined with two uplink sites located in the same plane as the satellite's positional error. For uplink sites exclusively within Europe and a satellite station-keeping accuracy of +/- 0.05°, this would result in a maximum variation of around +/- 10 $\mu$s, equivalent to +/-3 km. For worldwide uplinking the error could reach +/- 20 km (+/- 67 $\mu$s).

Slant path calculations are generally based on the assumption that the Earth is a uniform sphere. In reality it is an irregular ellipsoid, with a polar radius of 6256.74 km, and an equatorial radius of 6278.12 km, meaning the Earth is slightly 'wider' E-W than it is 'tall' N-S. While slant path length calculations generally use an average figure for the radius, this is not accurate enough for the TDM application. In addition,

the 'radius' of the Earth varies along any circumference due to further irregularities in the geodetic sphere. Therefore, if the Earth is incorrectly assumed to be a regular sphere, then the slant path distance may be in error by perhaps +/- 10 km, equivalent to a timing error of +/- 33 $\mu$s.

Several geodetic models have been proposed to approximate the Earth's shape, with GPS for example using "WGS 84". This enables errors due to ellipsoid geometry to be reduced to just a few metres.

The Earth station's height above sea level can also contribute to a timing error if it is located near the sub-satellite point. Mexico City, the uplink location for our first Eu-147 DAB satellite tests, is at an altitude of around 2 km above sea level.

Each of the contributing uplinks will need to be synchronised to a common time reference. The Global Positioning System (GPS) is a relatively low cost method of global timekeeping and can provide synchronisation to an accuracy of around 1 $\mu$s anywhere in the world. With this application in mind, a pair of GPS based master reference clocks were tested and a histogram produced is shown in Figure 6.

The samples were taken over a period of several weeks, at irregular intervals of at least 15 minutes. As can be seen, there is a distinct fixed offset between the two receivers (an average of 130 ns) but excluding this offset, around 97% of the results show the receivers to be within 175 ns of each other. While the standard GPS specification provides a dithered signal accurate to within +/-340 ns of GPS time/UTC for 95% of the time, the affect of the GPS receiver's flywheel circuitry smooths out the short term phase noise giving a better result.

While the antennas of the two GPS receiver used for the test were located only 0.3 metres apart, the manufacturers claim that similar results would be obtained if the receivers were thousands of miles apart.

The effect of the ionosphere varies depending mainly on sunspot activity, time of day, and path length through the ionosphere (which in turn depends on the satellite's elevation angle). The error contribution for the downlink path at 1.5 Ghz is likely to be less than 20 metres and will be common to all contributions. Atmospheric refraction on the uplink paths (typically 14 Ghz) is likely to be less than 1 metre (3 ns) and so will have a negligible affect on any particular uplink contribution.

Even a transparent transponder satellite will experience a small throughput delay, due mainly to filtering. This delay will be common to all contributions.

It has been shown above that there are several factors which will influence the accuracy which is achievable from a slant path distance calculation, and these are summarised in the table below. Some factors only cause an overall delay to the composite signal which is of little importance. Others (marked with a *) create a synchronisation error which may need to be compensated for. The figures given are 'typical worse case' examples.

| **Parameters:** | **Distance Error** | **Time Error** |
|---|---|---|
| 1. Irregular ellipsoid geometry of Earth | 10 km | 33 $\mu$s |
| 2. Height of earth station a.s.l. | 2 km | 6.7 $\mu$s |

| | | | |
|---|---|---|---|
| 3. | Atmospheric refraction (downlink @ 1.5 Ghz) | 20 metres | 67 ns |
| 4. | Satellite processing delay | 1 km | 3.3 $\mu s$ |
| 5. | Station keeping accuracy of satellite | 80 km | 266 $\mu s$ |
| | *[Differential error due to station keeping]* | *6 km** | *20 $\mu s$*]* |
| 6. | Synchronisation clock | 300 metres* | 1 $\mu s$* |
| | ***Differential errors** (creating synchronisation errors) | **6.3 km** | **21 $\mu s$** |

Therefore, under poor conditions the timing change between *two* uplink stations in widely separated locations could be double this figure at **42$\mu$s**.

While several factors cause a delay common across all uplinks this can be compensated for with a fixed delay, but the time-varying differential error due to satellite drift and GPS receiver clock error will always remain and, depending on the uplink location, this could be significant. Using DAB transmission Mode III the guard interval is only 31 $\mu s$, and in a hybrid satellite / terrestrial gap filler system, the erosion of the guard interval due to synchronisation errors would be particularly detrimental.

While the fixed components can all be compensated for by using the programmable internal delay of the COFDM generator, the time varying components may need to be eliminated by some form of closed loop control system based on the composite broadcast signal received at each slave uplink site as discussed earlier.

In a single uplink application the up-converter which mixes the signal to its final uplink frequency need not be

particularly stable as the receiver's AFC is capable of compensating for some error. However, in the COFDM uplink multiplexing system, the receiver's AFC and phase reference circuitry operate only on the first symbol of the DAB frame, and therefore only "tune in" to the master station. Switching to a different signal (i.e. a slave contribution) part way through the frame means a step change in the frequency, and any frequency difference gives rise to a loss of ruggedness of the signal. Therefore, each uplink site must employ a highly stable up-converter. The fact that Eu-147 uses differential coding is of benefit here, as it is the phase change between symbols which is important rather than absolute phase. A frequency reference with a short term (1000 seconds) frequency accuracy of <5 in $10^{10}$ is typically available from GPS clock receives which could assist in frequency matching of all slave stations.

Doppler Shift

Geostationary satellites do not normally create any significant doppler shift of their own due to their fixed orbit (but a mobile terrestrial receiver will experience some doppler shift due to its own velocity unless the satellite is directly overhead). However, doppler shift may be a problem during a repositioning manoeuvre (when compensating for orbital drift), when the satellite may have to move many kilometres in a short period of time.

The frequency shift is caused by two components. The frequency of the uplink transmission (typically at Ku band, 14 Ghz) will appear to be slightly altered, while the frequency of the downlink (broadcast signal) will also change, and in the same direction, compounding the problem. However, because doppler shift is proportional

to frequency, the uplink accounts for around 90% of any frequency change. A fixed frequency error throughout the transmission frame is not a problem as it can be tracked by the AFC circuitry in the consumer's receiver. But in an uplink multiplexing arrangement, the doppler could create a step change in frequency part way through the frame, thereby degrading the quality of the slave contributions.

As the satellite undergoes its repositioning manoeuvre, each uplink signal may experience a different doppler shift, the magnitude of which will vary with the direction of movement of the satellite. The difference between the frequency shifts of the transmissions from the individual uplink sites depends on their geographical separation (in a similar way to the change in time synchronisation with satellite movement).

Again, the frequency change is dependant on the satellite's velocity (i.e. speed and direction) and the geographical location of the uplink sites. The worse case situation would be between two uplinks at the extreme (5° elevation) and opposite edges of a global uplink coverage zone, with the satellite moving in the same plane. This could create a frequency step of approximately 15V Hz, where V is the velocity in metres/sec, (however this is a rather extreme and unlikely case). Monitoring the frequency transmitted by the satellite at each uplink site enables automatic feedback control of the uplink transmission to be achieved.

Repositioning is only likely to occur every few weeks and it may be possible to request that it happens at a convenient time of the night when audience figures are low (e.g. 04.00 am).

For a power limited system such as this where the link margin may well be just 2 dB, it is vital that the downlink power budget is maximised, and so the satellite must operate at its optimum power output. This requires that the power level of each contribution to the COFDM transmission frame should be matched to within a fraction of a dB when it arrives at the satellite's input antenna. Gain compensation for incorrect uplink power levels will not be possible at the satellite, and so each uplink site will have the responsibility of ensuring that its own power level matches that of the master station.

The signal levels received at the satellite will depend on several factors - nominal uplink power setting, amplifier efficiency, transmitting antenna misalignment, equipment ageing, satellite receiving antenna gain variation with direction, spreading loss (due to the geographical location of the uplink site). In addition to these "fixed" variables the effect of atmospheric attenuation, and in particular the affects of local rain can change the effective *uplink* power level by 1 or 2 dB in only a few seconds.

The simplest way of achieving a constant envelope would be to monitor the broadcast signal at each slave site, and adjust the local uplink power as required. This would then take into account all the above variables and can be done automatically with a feedback loop.

**MULTIPLEX CONFIGURATION AND THE FAST INFORMATION CHANNEL**

In a normal single transmission chain system, the multiplex can be reconfigured dynamically, with the corresponding Multiplex Configuration Information (MCI) being signalled in the Fast Information Channel (FIC). In the TDM uplinking system it is not possible to time

multiplex the FIC data and so the master uplink station alone would provide the FIC and hence the MCI. This leads to some limitations in the way the multiplex can be reconfigured. For the multiplex to operate correctly it is essential that the data supplied by the MCI matches the actual configuration transmitted by each of the slave uplink sites.

The simplest method is obviously for all parties to agree on a semi-permanent multiplex configuration. The MCI will therefore only need to be changed on the rare occasion when a radical reconfiguration is required, and a suitable scheme could be developed to ensure that all parties complied with the pre-agreed changes.

Where a multiplex reconfiguration is limited to an internal change at one uplink site only, so that the capacity transmitted from that site (i.e. the total number of symbols) remained constant, only the master and that particular slave site need to make any changes. However, a multiplex reconfiguration may require a change in the total capacity contributed by a particular site, and this would involve notifying the other affected sites of the impending change.

When the total number of symbols per frame transmitted by an uplink is to change, a complication arises. The multiplex reconfiguration is not an instant event due to the affect of the time interleaving process, and to comply thoroughly with the Eu-147 specification, would require that some of the data would continue to originate from the first uplink even after the second uplink had started to contribute to its newly acquired symbol. The mapping of bits onto carriers and the necessary switching is extremely complex and while such a

scheme would not be impossible to implement, the benefits would be perhaps marginal.

It is worth noting that while terrestrial DAB will experience roughly the same change in demand across all services through the day, for satellite DAB the situation is different. The different time zones covered by a single beam could mean that a particular service aimed primarily at the eastern edge of its coverage may require a larger proportion of the multiplex at the peak listening time of the day, and a few hours later may wish to relinquish some of its capacity to an uplink site primarily serving the western edge of the downlink beam as this region approaches its own peak listening time.

One of the disadvantages with any TDMA like scheme is that the transmission equipment must be rated for the peak power levels, even though the average power output may be relatively low. For example, the normal RF power requirement for a DAB uplink, supplying a full multiplex, is typically around 10 Watts. However, the amplifier would need to be backed off by several dB from saturation (to prevent non-linear distortion), and so will need to be rated at around 30 Watts. A single uplink of 128 kbits/s contributing to the 1.152 Mbits/s DAB multiplex will only be operating at 11% duty cycle - in this case with an average power of 1.1 Watts but even so the amplifier used must still be rated at 30 Watts.

For each of the specified DAB operating modes, the carrier spacing is approximately proportional to the transmitting frequency. This means that the affects of oscillator phase noise and doppler shift, which scale with frequency, also remain constant. While for DAB Mode III the carrier spacing of 8 kHz is adequate for the transmitting frequency of around 1.5 Ghz, the *uplink*

*frequency* is likely to be several times greater than this, with most uplinks operating at around 6 Ghz (C-band) and 14 Ghz (Ku-band). Any phase noise in the up-converter therefore contributes to a degradation of the DAB signal, and so this component must be carefully chosen.

With any time multiplexed system it is vital that every contributing source is operating correctly synchronised so that it only transmits during its allocated period, otherwise errors will occur. It was pointed out in the section describing timing accuracy that a data collision may not only cause a data loss, and in severe cases may also cause amplifier overload or a reduction in available power for other users of the transponder.

In particular, the first few data bits of every MPEG audio frame carry the very important MPEG header bits used for audio frame synchronisation. This data is mapped into the first symbol of the DAB audio frame, and so even a one symbol overlap due to an incorrect configuration may cause a complete loss of audio for the second contribution. (Although the ETSI standard uses a 16-bit time interleaving process to shuffle the data around between frames, it does not change the relative position of the data within the frame, making the data particularly sensitive to frame rate effects).

In the Eu-147 system, the null symbol is essential for coarse synchronisation in the time domain and so if a slave uplink fault condition creates a gap, this can be misinterpreted as a null symbol, thereby preventing the receiver from acquiring synchronisation, and therefore resulting in *non* of the services on that multiplex being received.

In the event of a slave uplink being unable to provide a correctly timed signal at the correct frequency and with an appropriate power level it would be wise for it to drop out immediately, and be replaced by the master uplink for the duration of the fault. Therefore the master uplink station needs the flexibility to allow it to cover for fault conditions at any of the slave sites.

The cost of the *additional* equipment required to implement a time division multiplexed uplink, as described is relatively small. On the top of the usual equipment required for a 'hub' earth station (multiplexer, COFDM generator, upconverter and power amplifier), the only two extra pieces of equipment required for TDM operation are the GPS master clock receiver, costing around £2,000 and an RF switching unit, which if manufactured commercially would cost approximately £2,000.

CLAIMS

1. A method for transmitting a multi-carrier signal having a regular frame structure and symbol rate comprised of contributions from a plurality of different transmitters comprising the steps of:

a) transmitting the contributions from each transmitter to a central transmitter in preassigned time slots;

b) retransmitting the thus received contributions as a single signal over a predetermined area of coverage; and

c) inserting at the start of each contribution a dummy symbol for use as a phase reference for demodulating succeeding symbols in that contribution.

2. A method according to claim 1 in which the central transmitter comprises a satellite in geostationary orbit and the plurality of transmitters comprise earth based transmitters.

3. A method according to claim 1 in which the central transmitter comprises a stratospheric platform in geostationary orbit and the plurality of transmitters comprise Earth based transmitters.

4. A method according to claim 2 or 3 including the step of providing a timing reference signal to each earth based transmitter.

5. A method according to claim 4 in which the step of providing a timing reference comprises detecting a

global timing signal transmitted by a global positioning system (GPS).

6. A method according to claim 2 or 3 comprising the step of providing common frequency reference signals to each Earth based transmitter.

7. A method according to any preceding claim including the step of delaying transmission of signals from each Earth station to the satellite in dependence on the position on the Earth's surface of each Earth station.

8. A method according to claim 7 including the step of monitoring at each Earth station the COFDM signal from the satellite and adjusting the delay applied to transmissions from the Earth station to compensate for any timing errors caused by other factors.

9. A method according to claim 8 in which timing errors are caused by the relative position and velocity of the satellite or stratospheric platform.

10. A method according to any preceding claim including the step of monitoring at each transmitter the timing and frequency of the contribution supplied by that transmitter after re-transmission by the central transmitter, and adjusting the timing and frequency of the signal to be transmitted in dependence on the received signal.

11. A method according to claim 10 in which the dummy symbol includes a predetermined pattern of data

which are used for monitoring the timing and frequency of signals received at each transmitter.

12. A method according to any preceding claim in which at least part of the dummy symbol is used to transmit data to dedicated receivers.

13. A method according to claim 12 in which the data for dedicated receivers is used as data for voice communication channel between Earth stations.

14. A method according to any preceding claim in which at least part of the dummy symbol is used as a data channel to supply data to the transmitter providing the first contribution in each frame of data for inclusion in an information signal defining the structure of the frame.

The Patent Office

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**Application No:** GB 9721862.2
**Claims searched:** 1 to 14

**Examiner:** Ken Long
**Date of search:** 15 April 1998

# Patents Act 1977
# Search Report under Section 17

**Databases searched:**

UK Patent Office collections, including GB, EP, WO & US patent specifications, in:

UK Cl (Ed.P): H4M (MTQA1-3 & MTQX1-3) & H4P (PAL, PSB & PAPS)

Int Cl (Ed.6): H04J 3/06 H04B 7/212 & H04L (7/04 & 27/26)

Other: NONE

**Documents considered to be relevant:**

| Category | Identity of document and relevant passage | | Relevant to claims |
|---|---|---|---|
| A | GB 2313527 A | MITSUBISHI | None |
| A | EP 0683576 A1 | HITACHI | None |
| A | WO 94/08405 A1 | MOTOROLA | None |
| A | US 4574379 | AT&T | None |

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|---|---|---|---|
| X | Document indicating lack of novelty or inventive step | A | Document indicating technological background and/or state of the art. |
| Y | Document indicating lack of inventive step if combined with one or more other documents of same category. | P | Document published on or after the declared priority date but before the filing date of this invention. |
| & | Member of the same patent family | E | Patent document published on or after, but with priority date earlier than, the filing date of this application. |

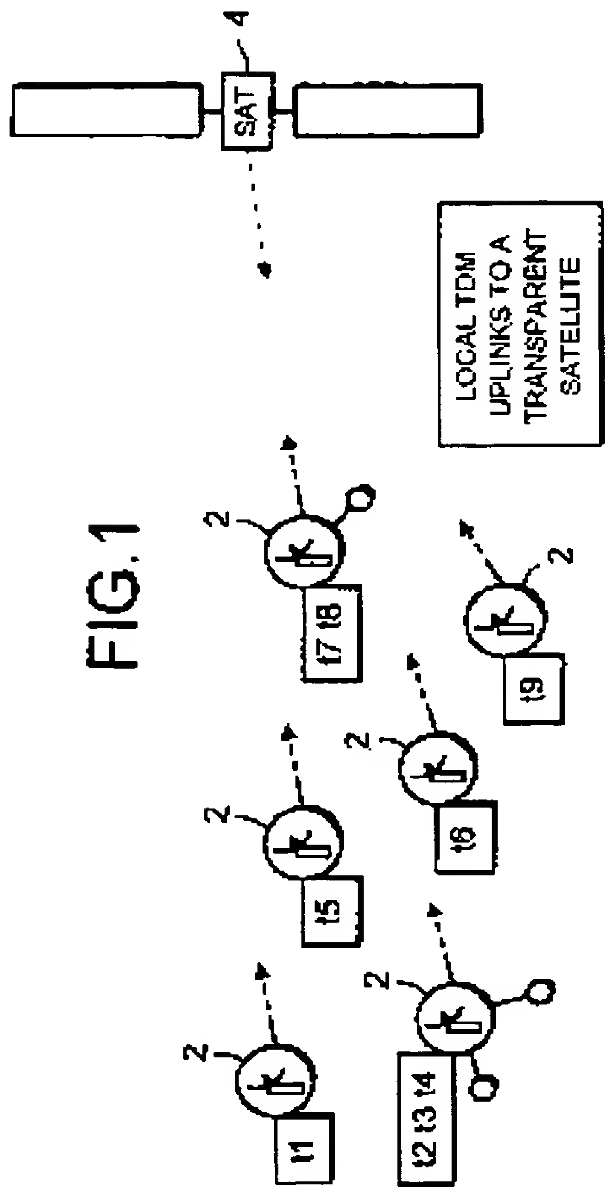

SAT
4
LOCAL TDM UPLINKS TO A TRANSPARENT SATELLITE
2
t1
t2 t3 t4
t5
t6
t7 t8
t9

FIG.1

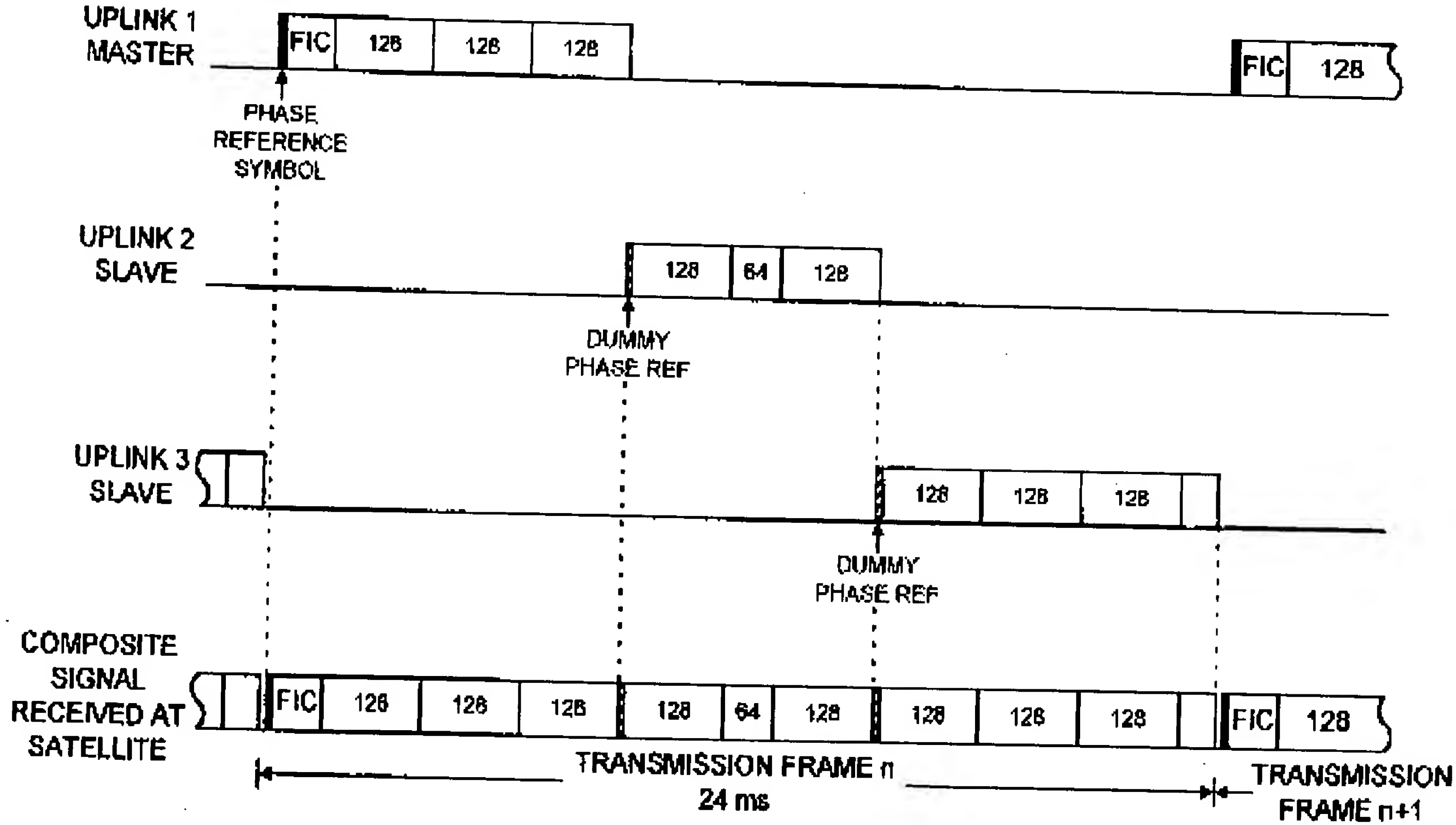

UPLINK 1
MASTER
FIC
128
128
128
FIC
128
PHASE
REFERENCE
SYMBOL
UPLINK 2
SLAVE
128
64
128
DUMMY
PHASE REF
UPLINK 3
SLAVE
128
128
128
DUMMY
PHASE REF
COMPOSITE
SIGNAL
RECEIVED AT
SATELLITE
FIC
128
128
128
128
64
128
128
128
128
FIC
128
TRANSMISSION FRAME n
24 ms
TRANSMISSION
FRAME n+1

FIG. 2

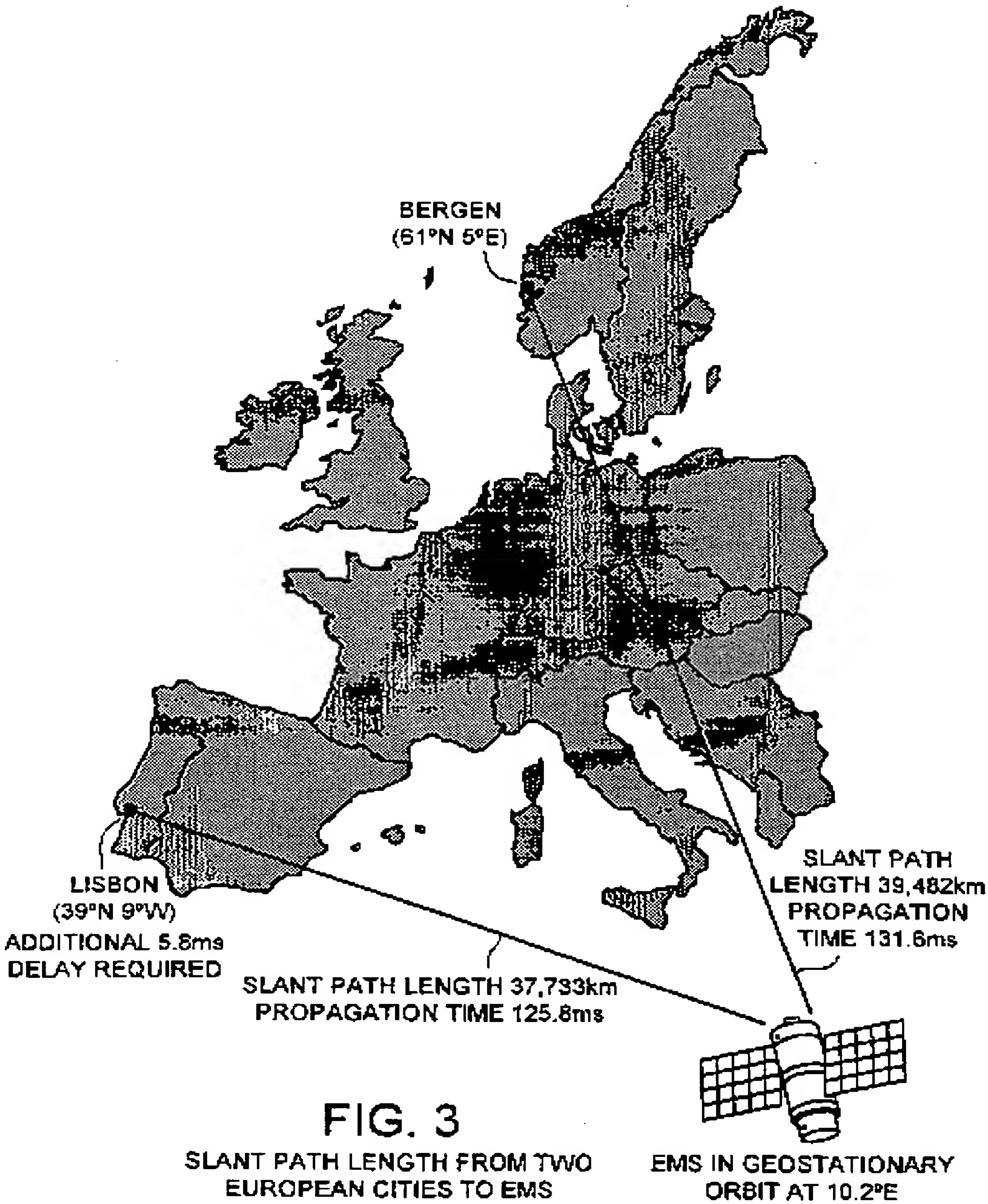
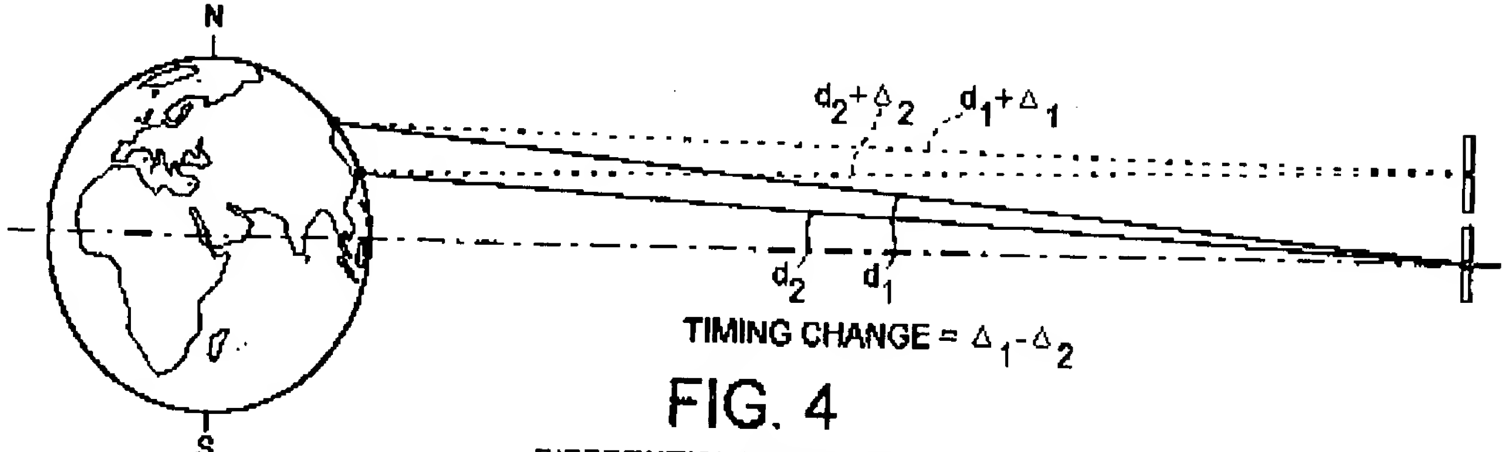



FIG. 3

SLANT PATH LENGTH FROM TWO
EUROPEAN CITIES TO EMS




TIMING CHANGE = $\Delta_1 - \Delta_2$

FIG. 4

DIFFERNTIAL RANGE ERROR

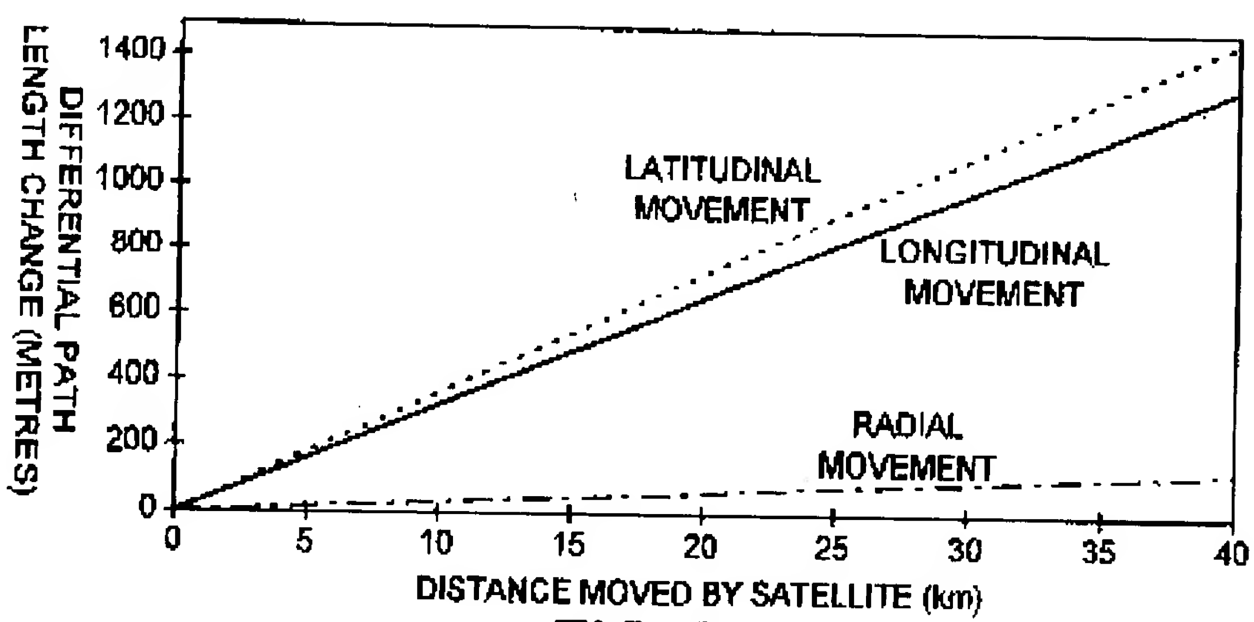



FIG. 5

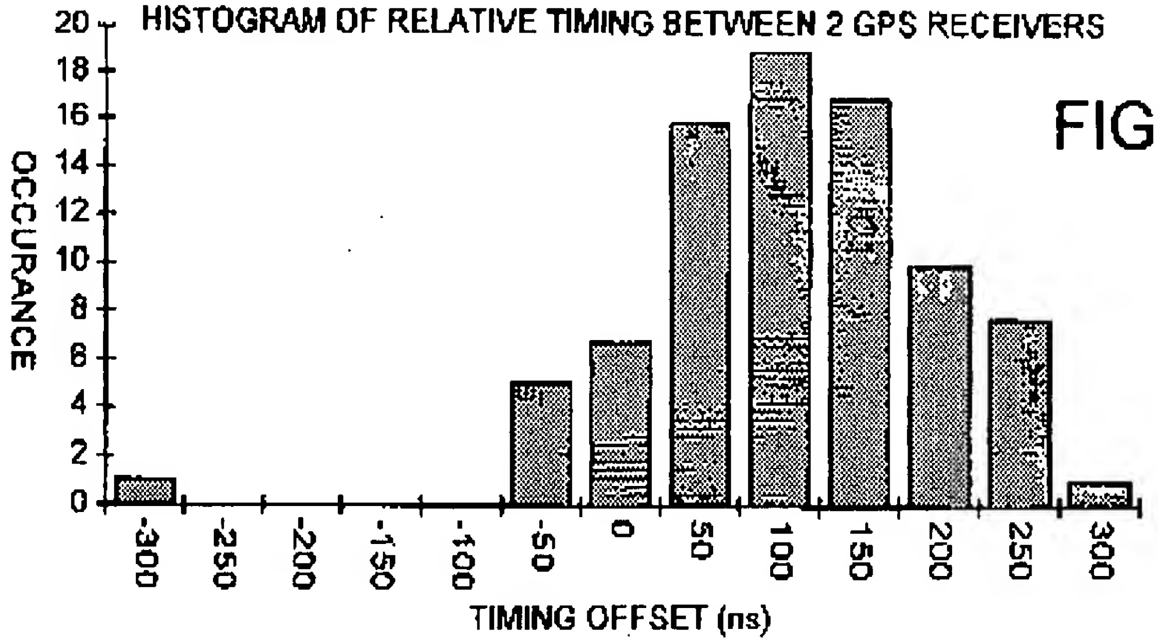

HISTOGRAM OF RELATIVE TIMING BETWEEN 2 GPS RECEIVERS
OCCURANCE
20
18
16
14
12
10
8
6
4
2
0
-300
-250
-200
-150
-100
-50
0
50
100
150
200
250
300
TIMING OFFSET (ns)

FIG. 6

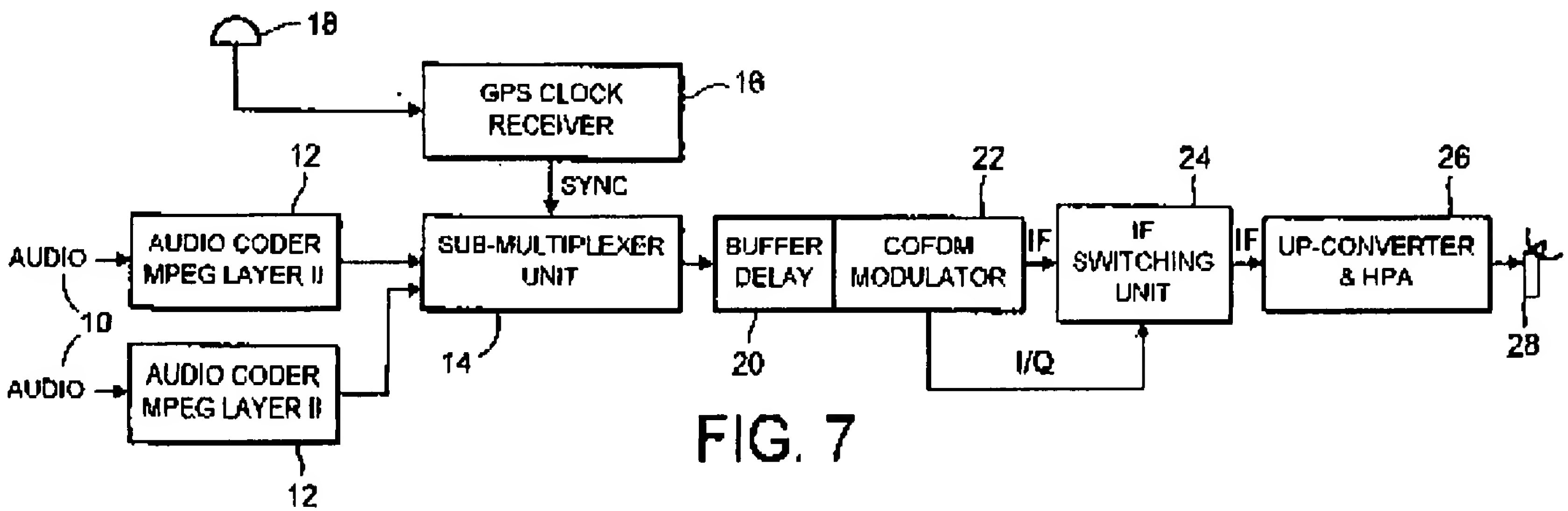

18
GPS CLOCK RECEIVER
16
SYNC
12
AUDIO
AUDIO CODER MPEG LAYER II
10
AUDIO
AUDIO CODER MPEG LAYER II
12
SUB-MULTIPLEXER UNIT
14
BUFFER DELAY
20
COFDM MODULATOR
22
IF
IF SWITCHING UNIT
24
I/Q
IF
UP-CONVERTER & HPA
26
28

FIG. 7